Report as of FY2010 for 2010OK192G: "Scale Dependent Phosphorus Leaching in Alluvial Floodplains"

Publications

Project 2010OK192G has resulted in no reported publications as of FY2010.

Report Follows

First Annual Progress Report

SCALE-DEPENDENT PHOSPHORUS LEACHING IN ALLUVIAL FLOODPLAINS

USGS Award No. G10AP00137

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Brian Haggard, Andrew Sharpley, and Phil Hayes
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This report is the first of two annual progress reports for this two-year project.

Because it is concise, no executive summary is provided.

SCALE-DEPENDENT PHOSPHORUS LEACHING IN ALLUVIAL FLOODPLAINS
USGS AWARD NO. G10AP00137

Principal Investigators:

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Congressional District: 2nd and 3rd in Oklahoma; 3rd in Arkansas

Focus Category: AG, GEOMOR, GW, HYDROL, NPP, NU, ST, SW, WQL

(1) Problem and Research Objectives

This research hypothesizes that macropores and gravel outcrops in alluvial floodplains have a significant, scale-dependent impact on contaminant leaching through soils; therefore, both soil matrix and macropore infiltration must be accounted for in an analysis of nutrient transport. However, quantifying the impact and spatial variability of macropores and gravel outcrops in the subsurface is difficult, if not impossible, without innovative field studies. This research proposes an innovative plot design that combines these and other methods in order to characterize water and phosphorus movement through alluvial soils.

The specific objectives of this research are twofold. The first objective is to quantify the phosphorus (P) transport capacity of heterogeneous, gravel soils common in the Ozark ecoregion. Two characteristics of the soil are expected to promote greater infiltration and contaminant transport than initially expected: (1) macropores or large openings (greater than 1-mm) in the soil (Thomas and Phillips, 1979; Akay et al., 2008; Najm et al., 2010) and (2) gravel outcrops at the soil surface (Heeren et al., 2010). This research will estimate P concentration and P load of water entering the gravelly subsoil from the soil surface for various topsoil depths, storm sizes, and initial P concentrations. Second, the impact of experimental scale on results from P leaching studies will be evaluated. If a material property is measured for identical samples except at various sample sizes, a representative element volume (REV) curve can be generated showing large variability below the REV. This provides a helpful framework for evaluating scales in P leaching. What minimum land area is necessary to adequately measure P leaching? It is hypothesized that measured P leaching (kg m^{-2} s^{-1}) will generally increase as the scale increases from point (10^{-3} m^2) to plot (10^2 m^2) scales. This will be evaluated by measuring P leaching at the point scale in the laboratory and at plot scales with bermed infiltration experiments for three plot sizes (approximately 10^0, 10^1, and 10^2 m^2).

If subsurface transport of P to alluvial groundwater is significant, these data will be critical for identifying appropriate conservation practices based on topsoil thickness. Riparian buffers are primarily aimed at reducing surface runoff contributions of P; however, their effectiveness within floodplains may be significantly reduced when considering heterogeneous subsurface pathways.

Methodology and Principal Findings/Significance

The three selected riparian floodplain sites are located in the Ozark region of northeastern Oklahoma and western Arkansas. The Ozark ecoregion of Missouri, Arkansas, and Oklahoma is characterized by karst topography, including caves, springs, sink holes, and losing streams. The erosion of carbonate bedrock (primarily limestone) by slightly acidic water has left a large residuum of chert gravel in Ozark soils, with floodplains generally consisting of coarse chert gravel overlain by a mantle of gravelly loam or silt loam (Figure 1). The three floodplain sites are located adjacent to the Barren Fork Creek, Pumpkin Hollow and Clear Creek (Figure 2).

Figure 1. Floodplains in the Ozark ecoregion generally consist of coarse chert gravel overlain by a mantle (1-300 cm) of topsoil.

Figure 2. Location of riparian floodplain sites in the Ozark ecoregion of Oklahoma and Arkansas.

Barren Fork Creek Site (Oklahoma)

The Barren Fork Creek site, five miles east of Tahlequah, Oklahoma, in Cherokee county (latitude: 35.90°, longitude: -94.85°), is located just downstream of the Eldon U.S. Geological Survey (USGS) gage station (07197000). A tributary of the Illinois River, the Barren Fork Creek has a median daily flow of 3.6 m^3 s^{-1} and an estimated watershed size of 845 km^2 at the study site. Historical aerial photographs of the site demonstrate the recent geomorphic activity including an abandoned stream channel that historically flowed in a more westerly direction than its current southwestern flow path (Figure 3).

Fuchs et al. (2009) described some of the soil and hydraulic characteristics of the Barren Fork Creek floodplain site. The floodplain consists of alluvial gravel deposits underlying 0.5 to 1.0 m of topsoil (Razort gravelly loam). Topsoil infiltration rates are reported to range between 1 and 4 m/d based on USDA soil surveys. The gravel subsoil, classified as coarse gravel, consists of approximately 80% (by mass) of particle diameters greater than 2.0 mm, with an average particle size (d_{50}) of 13 mm. Estimates of hydraulic conductivity for the gravel subsoil range between 140 and 230 m d^{-1} based on falling-head trench tests (Fuchs et al., 2009). Soil particles less than 2.0 mm in the gravelly subsoil consist of secondary minerals, such as kaolinte and noncrystalline Al and Fe oxyhydroxides. Ammonium oxalate extractions on this finer material estimated initial phosphorus saturation levels of 4.2% to 8.4% (Fuchs et al., 2009).

Figure 3. Aerial photos for 2003 (left) and 2008 (right) show the southward migration of the stream toward the bluff and the large deposits of gravel in the current and abandoned stream channels. The study site is the hay field in the south-central portion of each photo (red arrow).

The floodplain site is a hay field with occasional trees (Figure 4). The field has a Soil Test Phosphorus (STP) of 33 mg/kg (59 lb/ac) and has not received fertilizer for several years. The southern border of the floodplain is a bedrock bluff that rises approximately 5 to 10 m above the floodplain elevation and limits channel migration to the south. The floodplain width at the study site is 20 to 100 m from the streambank (based on the 100 year floodplain); however, water was observed 200 m from the streambank (to the bluff) during a 6 year recurrence interval flow event (Figure 4).

Figure 4. The Barren Fork site is a hay field (left). The site becomes completely inundated during large flow events (right).

Pumpkin Hollow Site (Oklahoma)

The Pumpkin Hollow site, 12 miles northeast of Tahlequah, Oklahoma, in Cherokee County (Figure 5, latitude: 36.02°, longitude: -94.81°) has an estimated watershed area of 15 km^2. A small tributary of the Illinois River, Pumpkin Hollow is an ephemeral stream in its upper reaches. The Pumpkin Hollow site is pasture for cattle (Figure 6). The entire floodplain is 120 to 130 m across. Soils in the study area include Razort gravelly loam and Elsah very gravelly loam.

Figure 5. Pumpkin Hollow is a narrow valley ascending from the Illinois River to the plateau.

Figure 6. The Pumpkin Hollow site in spring (left) and winter (right). The site includes soils with shallow layers of topsoil and gravel.

Clear Creek Site (Arkansas)

The Clear Creek site is 5 miles northwest of Fayetteville, Arkansas, in Washington County (Figure 7, latitude: 36.125°, longitude: -94.235°). Clear Creek is a fourth order stream, and is a tributary to the Illinois River. Streamflow during baseflow conditions is estimated to be around 0.5 cms. The Clear Creek site is also pasture for cattle (Figure 8). The floodplain is approximately 300 to 400 m across. The soils included intermixed layers of gravel and silt loam (Figure 8).

Figure 7. Clear Creek and an overflow channel at the Clear Creek floodplain site.

Figure 8. The Clear Creek site is pasture (left). Soils are composed of gravel and silt loam alluvial deposits (right).

Electrical Resistivity Imaging

Electrical Resistivity Imaging (ERI) is a geophysical method commonly used for near-surface investigations which measures the resistance of earth materials to the flow of DC current between two source electrodes. The method is popular because it is efficient and relatively unaffected by many environmental factors that confound other geophysical methods. According to Archie's Law (Archie, 1942), earth materials offer differing resistance to current depending on grain size, surface electrical properties, pore saturation, and the ionic content of pore fluids.

Normalizing the measured resistance by the area of the subsurface through which the current passes and the distance between the source electrodes produces resistivity, reported in ohmmeters (Ω-m), a property of the subsurface material (McNeill, 1980). Mathematical inversion of the measured voltages produces a two-dimensional profile of the subsurface showing areas of differing resistivity (Loke and Dahlin, 2002, Halihan et al., 2005).

ERI data were collected using a SuperSting R8/IP Earth Resistivity Meter (Advanced GeoSciences Inc., Austin, TX) with a 56-electrode array. Fourteen lines were collected at the Barren Fork Creek site, three at the Pumpkin Hollow site, and eight lines at the Clear Creek site. One line at the Barren Fork Creek site and all of the lines at Pumpkin Hollow were “roll-along” lines that consisted of sequential ERI images with one-quarter overlap of electrodes. The profiles at the Barren Fork Creek site employed electrode spacing of 0.5, 1.0, 1.5, 2.0 and 2.5 m with associated depths of investigation of approximately 7.5, 15.0, 17.0, 22.5 and 25.0 m, respectively. All other sites utilized a 1.0-m spacing. The area of interest in each study site was less than 3 m below the ground surface and thus well within the ERI window. The resistivity sampling and subsequent inversion utilized a proprietary routine devised by Halihan et al. (2005), which produced higher resolution images than conventional techniques.

The OhmMapper (Geometrics, San Jose, CA), a capacitively-coupled dipole-dipole array, was effectively deployed at the relatively open Barren Fork Creek site for large scale mapping. The system used a 40 m array (five 5 m transmitter dipoles and one 5 m receiver dipole with a 10 m separation) that was pulled behind an ATV. Two data readings per second were collected to create long and data-dense vertical profiles. The depth of investigation was limited to 3 to 5 m. Positioning data for the ERI and OhmMapper were collected with a TopCon HyperLite Plus GPS with base station. Points were accurate to within 1 cm.

Barren Fork Creek

Resistivity at the Barren Fork Creek site appeared to conform generally to surface topography with higher elevations having higher resistivity, although the net relief was minor (~1 m). This was most evident in the OhmMapper resistivity profiles which covered most of the floodplain and which revealed a pattern of high and low resistivity that trended SW to NE (Figure 9). More precise imaging with reduced spatial coverage was obtained with the ERI. A composite ERI line collected from the site is shown in Figure 10. The line, which is approximately parallel to the stream, begins only 5 m from the stream. Gravel outcrops are indicated by gray colors reaching closer to the surface and will be the location for induced leaching experiments at different spatial scales at this site.

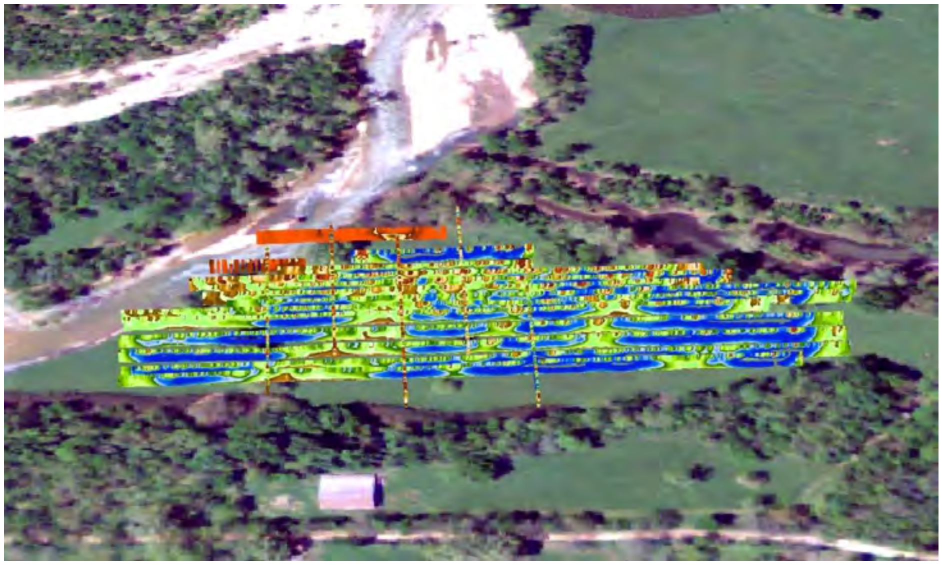


Figure 9. OhmMapper coverage of the Barren Fork Creek alluvial floodplain showing SW to NE trends of low (blue) and high (orange) resistivity. View is to the North and subsurface resistivity profiles are displayed above the aerial image for visualization purposes. Modified from Heeren et al. (2010).

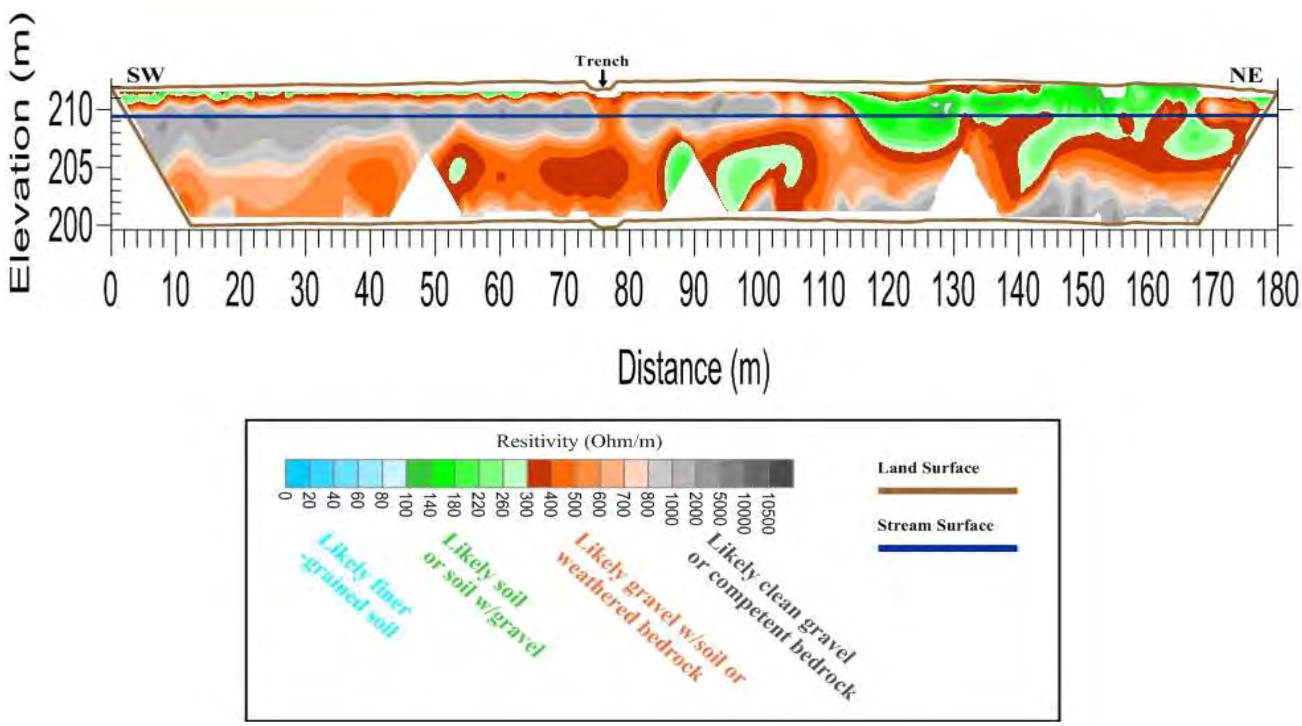


Figure 10. Composite SuperSting image, showing mapped electrical resistance (Ω-m), running southwest to northeast along a trench installed for studying subsurface phosphorus transport in the gravel subsoils by Fuchs et al. (2009). The *x*-axis represents the horizontal distance along the ground; the *y*-axis is elevation above mean sea level. Source: Heeren et al. (2010).

Pumpkin Hollow

Pumpkin Hollow differed from the other streams because it was a headwater stream with a smaller watershed area. The valley at the study site was approximately 200 m wide and the roll-along lines spanned nearly the entire valley width, crossing Pumpkin Hollow Creek at about the midpoint of the line. The ERI survey at Pumpkin Hollow consisted of three lines oriented W-E with 1 m electrode spacing, 12.5 m depth, and 97 m (lines 1-2 and 3-4) or 139 m (line 5-6-7) length (Figure 11).

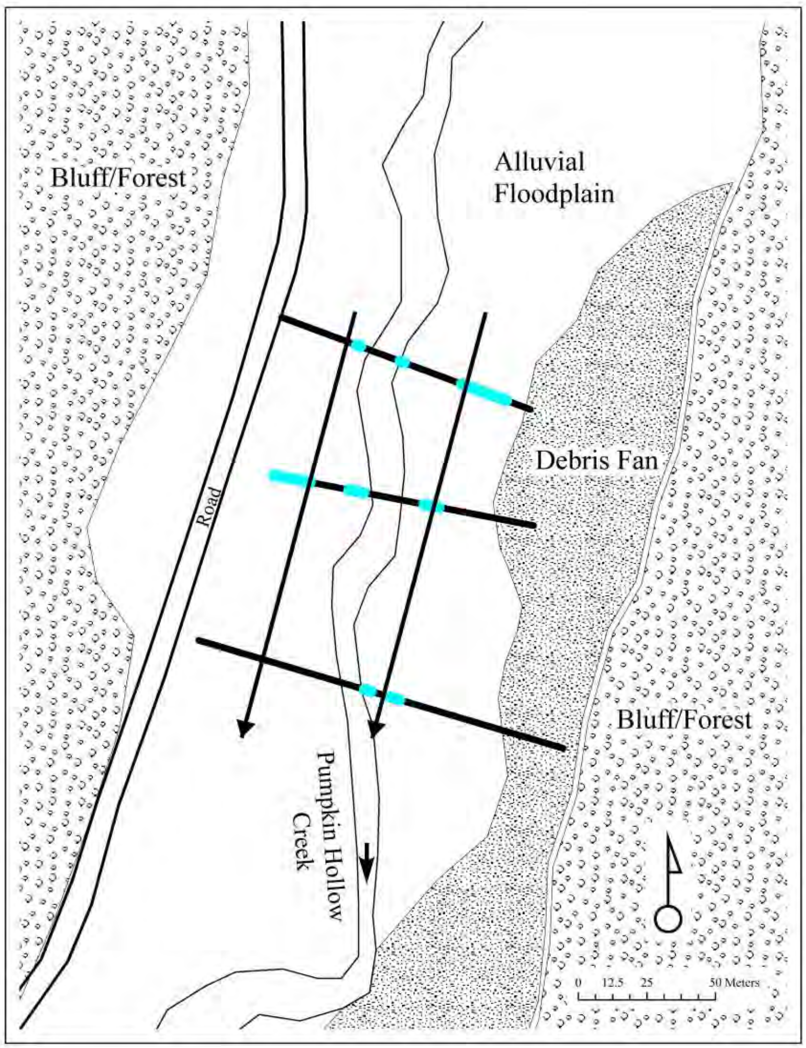


Figure 11. High resistivity feature locations on ERI lines at the Pumpkin Hollow site are shown in blue. Arrows represent potential connections between them and the direction of flow.

The Pumpkin Hollow ERI profiles also had a unique configuration consisting of a low resistivity layer between a high resistivity surface layer and high resistivity at depth (Figure 12). Observations at the site included the close proximity of large gravel debris fans originating from nearby upland areas. Jacobson and Gran (1999) noted similar pulses of gravel in Ozark streams in Missouri and Arkansas originating from 19th and early 20th century deforestation of plateau surfaces, implying that a possible interpretation of the low resistivity layer in the ERI profiles was a soil layer buried by gravel from the nearby plateau surfaces. The streambed elevation was approximately 262 m with the general floodplain surface being about 1 m above that elevation. The area of interest included the elevations above 262 m (note that the mean elevation was 262.9 m and that the maximum elevation 265 m occurred at the valley edge) and was therefore thin compared to the other study sites. The resistivity at Pumpkin Hollow ranged from 58 to 3110 Ω-m with a mean of 387 Ω-m. Like the other sites, the Pumpkin Hollow resistivity suggested a pattern of discrete areas of high resistance that indicated gravel outcrops (Figure 12). These were generally associated with topographic high areas and appeared to have the potential to direct flow down-valley parallel to the stream.

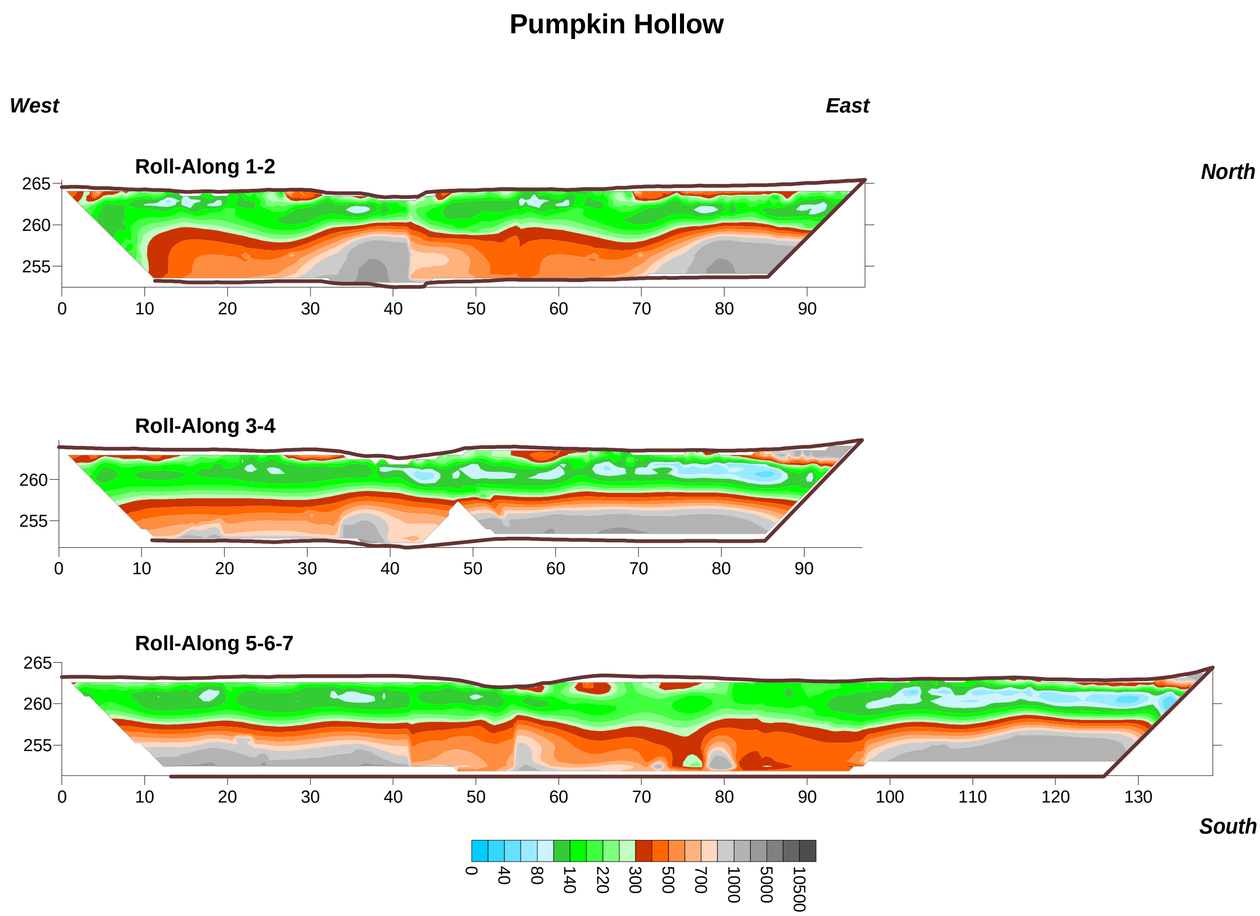
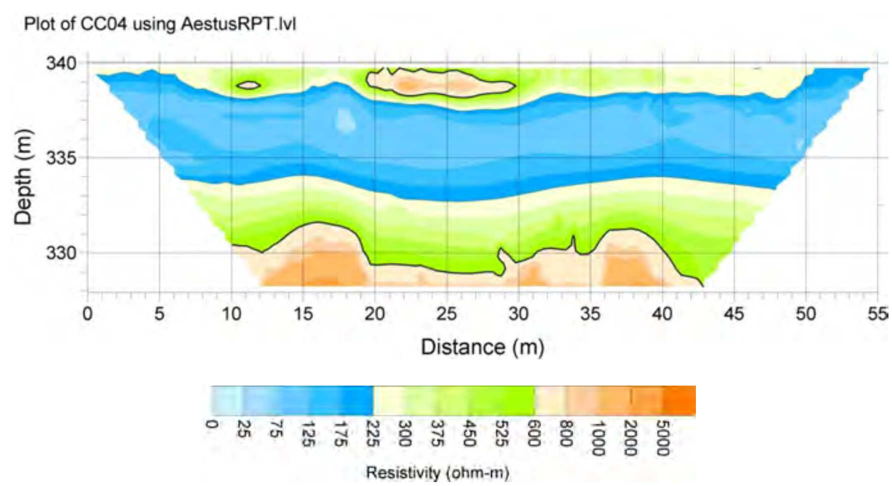


Figure 12. ERI images of three "roll-along" lines for the Pumpkin Hollow site. The *x*-axis represents the horizontal distance along the ground; the *y*-axis is elevation above mean sea level. The color bar is the electrical resistivity in Ohm-meters.

Clear Creek

Geophysical mapping was first performed between the overflow channel and Clear Creek shown in Figure 7; however, limited gravel outcrops were observed in this area and therefore the control (non-gravel outcrop) leaching experiments will be performed at this location (Figure 13a). Most of the shallow profile possessed electrical resistivities less than 450 Ω-m. On the east side of Clear Creek, layered profiles demonstrated the potential for lateral flow and transport to the stream, and this feature was clearly visible based on exposed streambanks and supported by the ERI data. Electrical resistivities at the surface were on the order of 600 to 1000 Ω-m with lower resistivity soils below this surface feature (Figure 13b).

(a)



(b)

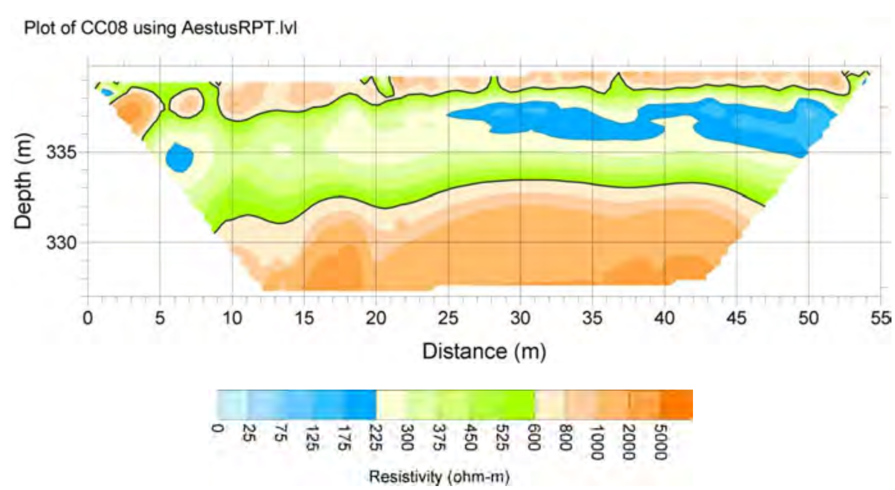


Figure 13. ERI images of two lines at the Clear Creek site where (a) is a line between the overflow channel and the creek with limited gravel outcrop area and (b) is a line on the east side of Clear Creek with gravel outcrops at the surface. The *x*-axis represents the horizontal distance along the ground; the *y*-axis is elevation above mean sea level.

Point Scale Laboratory Testing: Flow-Cell Experiments

Fine material (diameter less than 2.0 mm) from the Clear Creek site in Arkansas was used in laboratory flow-through experiments to investigate the P sorption characteristics with respect to the flow velocity (DeSutter et. al., 2006). Approximately 5.0 g of the fine materials was placed in each flow-through cell. A Whatman 42 filter was placed at the bottom of each cell to prevent the fine material from passing through the bottom. Each cell had a nozzle at the bottom with a hose running from the nozzle to a peristaltic pump (Figure 14). The pump pulled water with predetermined P and potassium chloride (KCl) concentrations through the cells and fine material at a known flow rate (mL/min).

Two different flow rates were used on the peristaltic pumps to evaluate the effect of velocity on P sorption. The flow rates were 0.20 mL/min for the low flow experiments and 0.75 mL/min for the high flow experiments. These flow rates corresponded to average flow velocities of 0.42 and 1.59 m/d, respectively. First, a 0.01M KCl solution was pulled through the soil to determine the background P that was removed from the soil. Then, a KH_2PO_4 and 0.01M KCl solution was injected into each cell at different concentrations (1.0 to 10.0 mg/L of P) and kept at a constant head using a Mariott bottle system (Figure 14). The experiments were run for approximately 8 hours. Samples were taken periodically throughout each experiment. The samples were analyzed in the laboratory for P using the Murphy-Riley (1962) method.

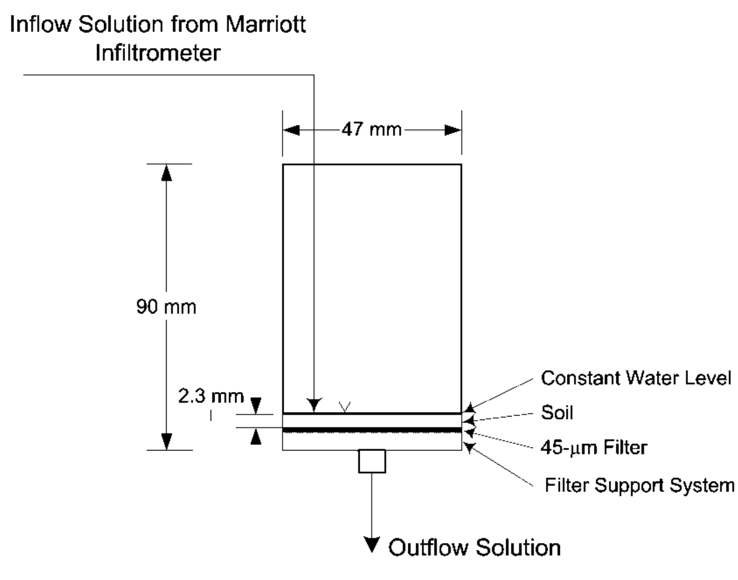
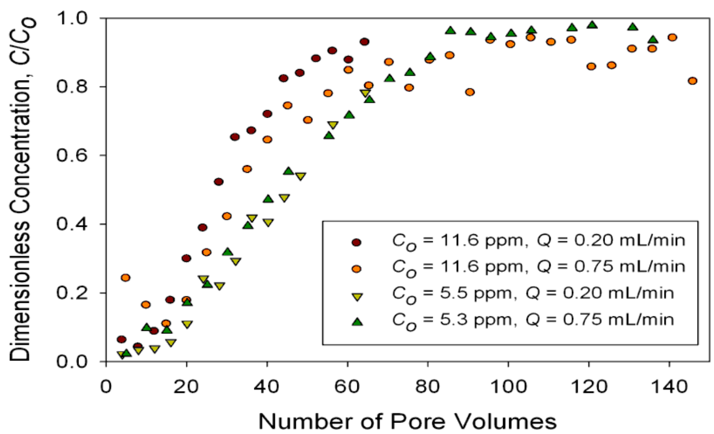


Figure 14. Laboratory flow-through experimental setup. The experimental setup follows that of DeSutter et al. (2006) and Fuchs et al. (2009).

Data were analyzed based on concentrations of P in the outflow compared to the total amount of P added to the system for both low flow and high flow scenarios. The principle of this method was that the measured P concentrations in the outflow should be approximately equal if flow velocity does not have an effect on P sorption. The mass of P added per kilogram of soil (mg P/ kg soil) was found by multiplying Q (mL/min) by the inflow P concentration (mg/L) and by the elapsed time of the experiment (min). These data were plotted against the P concentrations (mg/L) detected in the outflow solutions for both flow velocities. If equivalent sorption was occurring, the curves associated with each data set would be approximately equal. Data were also analyzed using contaminant transport theory relative to the dimensionless concentration and number of pore volumes passed through the soil.

Both the contaminant transport and load perspectives suggested that the flow velocities in the experimental range had no effect on the sorption capabilities of the system, but instead illustrated that the initial P concentrations were important (Figure 15).

(a)



(b)

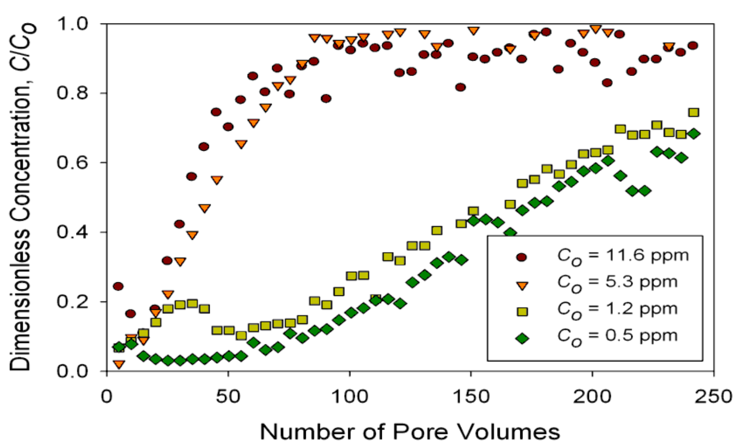


Figure 15. Phosphorus (P) breakthrough curves demonstrating (a) no influence of flow velocity on transport at the range of conditions studied and (b) influence of initial P concentration on transport.

Plot Scale Testing: Tracer/Rhodamine WT/P Infiltration Tests

As of May 2011, two leaching experiments (one 1 m^2 plot and one 9 m^2 plot) have been performed at both the Clear Creek and Pumpkin Hollow field sites. The Clear Creek experiments were performed in areas with limited gravel outcrops due to flooding in the area preventing access to the east side of Clear Creek. The Pumpkin Hollow leaching experiments were performed on areas of gravel outcrops as indicated from the electrical resistivity images.

A unique soil infiltration system was designed through the use of four steel connectors and 15.24-cm diameter hose (Figure 16). Specified lengths of the hose were placed in shallow trenches filled with bentonite clay, the hoses were then filled with water, and then the edges of the hoses were sealed with additional bentonite to prevent solutes from flowing underneath the berm. Therefore, water and solutes must travel through the soil matrix to leave the bermed area.

Figure 16. Filling of a 3 m by 3 m (9 m^2) bermed plot for the leaching experiments at Pumpkin Hollow with chloride tracer, Rhodamine WT, and phosphorus solution.

Prior to the leaching tests, two SuperSting DC resistivity meter (Advanced Geosciences, Inc., Austin, TX) electrode lines, crossing in the middle of the injection area, were setup to image the injection. Background images were obtained prior to water injection and then images were collected periodically throughout the experiment. The difference between the background image and the successive images will show the migration of the plume, and these images are currently being analyzed for each of the injection tests performed thus far.

Observation wells surrounding the plots were instrumented with water level loggers to automatically monitor water table elevation and temperature at 1-minute intervals during the experiments. Observation wells were installed to a depth of approximately 2.4 to 3.0 m at Clear Creek. Because of the unique layering at Pumpkin Hollow, both shallower (approximately 0.6 m below ground surface) and deeper (approximately 1.8 m below ground surface) observation wells were installed around the infiltration plot.

Stream water was pumped into the plot area through a water tank. A constant head of 3 to 5 cm was maintained inside the berm area. Pressure transducers were installed in the water tanks to monitor the water level change over time to quantify the total infiltration rate. Stream water was injected with a combination of potassium chloride (conservative and nonsorbing), Rhodamine WT (slightly sorbing), and P (highly sorbing). The target concentration in the ponded water was 100 mg/L chloride and Rhodamine WT, and 10 mg/L P (potassium phosphate). The inflow water was sampled throughout the experiment.

Conductivity sensors were used to indicate the initial detection of the leaching plume into the shallow groundwater based on periodic sampling from the observation wells. Approximately 250 mL samples were collected from each observation well at numerous times throughout the experiment from the top 10 to 25 cm of groundwater with a peristaltic pump using low-volume pumping as performed by Fuchs et al. (2009). Sampling continued for 24 to 48 hrs, or until the P concentration approached the inflow concentration in the ponded water. Samples from these first four leaching experiments are currently being tested for both total phosphorus and dissolved reactive phosphorus in the AWRC Water Quality Laboratory on the University of Arkansas campus.

Preliminary results from the early leaching tests are promising in terms of both the experimental design and results. Detection of Rhodamine WT was observed in deep observation wells at the Clear Creek site three to six hours after starting the leaching experiments, suggesting the presence of preferential flow. Tests at Pumpkin Hollow demonstrated rapid leaching in the shallow gravel layers at the soil surface and rapid lateral subsurface transport to the stream located approximately 15 m from the 9 m^2 plot. Rhodamine WT injected in the 9 m^2 plot at Pumpkin Hollow was visibly present in the stream approximately 1.5 hours after initiating the leaching experiment (Figure 17).

Figure 17. Leaching test on a 3 m by 3 m (9 m^2) plot at Pumpkin Hollow which demonstrated rapid leaching in the shallow gravel layers at the soil surface and rapid lateral subsurface transport to the stream located approximately 15 m from the plot. Rhodamine WT injected in the plot was visibly present in the soil approximately 1.5 hours after initiating the leaching experiment.

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(2) PUBLICATIONS

None to report at this time.

(3) INFORMATION TRANSFER PROGRAM

A project website on subsurface P transport has been created with links to relevant publications and data from the project (http://biosystems.okstate.edu/Home/gareyf/ AlluvialPTransport.htm). Because the results are preliminary at this time, no presentations have been given on the project, but multiple future presentations are planned. The PI and co-PIs were scheduled to give a field tour and research demonstration on April 27, 2011 in conjunction with a karst hydrology working group meeting of the USGS. However, due to flooding in Arkansas and Oklahoma, the field demonstration was cancelled. The research team has been invited to present initial research results to the Arkansas Water Quality Research Conference on July 6-7, 2011. The PI, co-PIs, and students will appear on an informative segment on the Oklahoma State University SUNUP

TV program for the Oklahoma agricultural community this summer. Research results and field methods will be incorporated immediately into an environmental contaminant transport class for graduate students this summer.

(4) STUDENT SUPPORT

Support has been provided for two graduate students (Ph.D. student in Biosystems and Agricultural Engineering at Oklahoma State and a Master of Science student in Environmental Sciences at Oklahoma State University) and two undergraduate students. Also, the research supported a 2010-2011 Oklahoma State University Wentz Research Scholars project for an additional undergraduate student.

Student Status	Number	Disciplines
Undergraduate	3	Biosystems Engineering
M.S.	1	Environmental Sciences (Geology)
Ph.D.	1	Biosystems Engineering
Post Doc		
Total	5	

(5) STUDENT INTERSHIP PROGRAM

No students completed an internship during the reporting period.

(6) NOTABLE ACHIEVEMENTS AND AWARDS

None to report at this time.